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The Effect of Renewable Energy Sources from Distributed Generation on Energy Losses in the Low Voltage Networks

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ABSTRACT*:* A In this paper, the effect of distributed generators, from renewable energy sources connected to the distribution network, on technical losses in the low voltage network is studied. This investigation is based on a case study in the low voltage networks of electricity distribution companies.The distribution network was designed and updated by means of the distribution generators model through the CYME program with the necessary network data for the analysis as these substations were represented. Two cases have been identified for the study, which are with and without distribution generators, and in each case, the energy losses are calculated.

KEYWORDS: Distribution Generators, Renewable Energy, Energy Losses, Low Voltage Network..

I.INTRODUCTION

Jordan is considered a fertile and attractive market for those wishing to invest in the energy sector, especially after the connection of renewable energy sources in 2012 to the Jordanian electrical system, and allowing small consumers to create and install renewable system sources, for their consumption through distribution networks [1, 2].The provision of energy in all its forms is one of the basic pillars of our modern world as energy security is one of the main objectives of the energy strategies announced in various countries of the world and most of our societies depend heavily on electricity. Electrical networks allow power distribution and delivery through the availability of infrastructures such as power plants or renewable energy sources (RES) to customers (factories and residences). As a natural consequence of any electrical system, there are energy losses from generation sources to the final consumer. These losses cause major problems including a decrease in the reliability and stability of the electrical system as well as large financial losses for electricity providers the problem is the loss of energy for any electrical network which is the difference between the amount of energy generated and the amount of energy imposed on the final consumer as it will allow studying the effect of distribution generators (DG) from renewable energy sources [3–5]. Availability of the distribution network for energy policymakers in Jordan a perception of its technical and economic implications.

In this paper, CYME software was used to analyze energy data and represent power substations with and without DG, CYME is a collection of applications consisting of analysis units. CYME is important for the most advanced analysis of transmission, Distribution, transportation, and industrial energy systems. CYME provides a list of program functions Solutions that address most aspects of energy system analysis: energy flow analysis, Emergency analysis, optimal energy flow analysis, error analysis, harmonic analysis, Transient stability analysis, crusher assessment analysis, wind power conversion systems, Analysis of voltage stability, monitoring of the protection, forecasting and history device Reliability assessment. In this paper, using CYME, the power flow analysis is designed to assist in the analysis of static emergencies associated with power flow. With it, the power engineer can create emergency events and single or multiple outage scenarios, and compare the results with the base-state network and connection data. The goal of power flow software is to analyze the steady-state performance of a power system under various operating conditions. It is the essential analysis tool for planning, designing, and operating any electrical power system.

II.DISTRIBUTION GENERATORS

The DG concept is not new in general, but it is growing more popular right now due to all of its benefits over central power producing units. There is no standardization in terms of its definition and scale, and it goes by several names in different nations, including decentralized generation, built-in generation, and distributed generation. [6]. Many

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researchers defined it in their own way, some of which, according to [7] DG was defined as a power source directly connected to the distribution network or in the customer's location of the meter, see Figure 1.

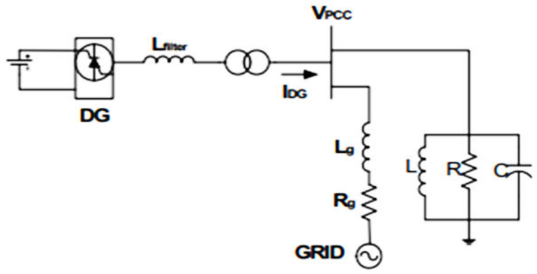

Fig. 1.A simple single line diagram of the system of a DG, Grid and RLC load

Distributed generation is a strategy that produces energy near to the final consumers by using small-scale technology. The modular (and occasionally renewable-energy) generators that make up DG technologies frequently have a variety of potential advantages. In many cases, distributed generators can provide lower-cost electricity and higher power reliability and security with fewer environmental consequences than can traditionally power generators the centralized generation remains the main source of electricity while distributed energy resources (DER) provide reliability, resilience, and transmission & distribution grades to the grid, see Figure 2.

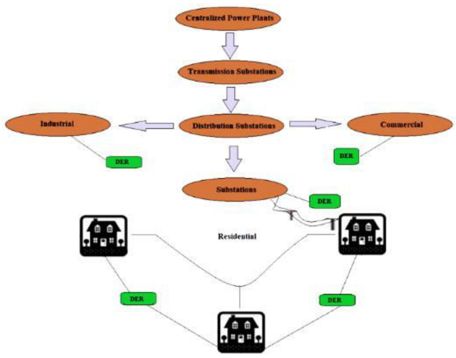

Fig. 2. DER Placement in Power System

Types of distribution generators

There are different types of DGs both conventional and renewable energy based below. These types of DGs should be compared with each other to help make the decision regarding which type is most appropriate to choose in different situations as shown in Figure 3.

Traditional combustion generators

Micro-turbine (MT) is small turbine technology that has a bright light future. They are combustion turbines of small capacity, which can work with natural gas, propane, and fuel oil. In a simple form, it consists of a compressor, burner, exhaust, small turbine, and generator. Sometimes, they just have a Single movable shaft, and use air or oil for lubrication.

MTs Small scale from 0.4-1 m3 in volume and 20-500 kW in volume. Unlike conventional combustion turbines, MTs operate at less Temperature pressure and higher speed (100,000 rpm). Which sometimes does not require a gearbox [8].

Non -traditional generators

Electrochemical devices: fuel cell (FC)

The fuel cell is a device that converts chemical energy into electrical power and heat energy through electrochemical reactions. As long as its fuels are supplied, it may be thought of as a battery that provides electric energy. FC does not require charging for the materials used during the electrochemical process, in contrast to batteries, because these components are continually available [9].

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Storage devices

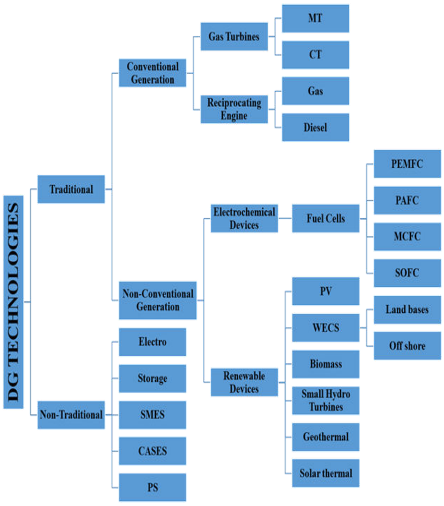

Fig.3. Distributed generation types and technologies

Battery-powered storage devices are charged during periods of low load demand and used as needed. In order to offer the necessary peak load demand, it is typically paired with other forms of DG types [10]. The term "deep cycle" refers to these batteries. Many charges and discharges of deep cycle batteries can be made without any failure or harm. These batteries contain a charging controller, which disconnects the charging process after the batteries are fully charged, protecting them from overcharging and over discharging. The length of time these batteries are discharged depends on their sizes.

Renewable devices

Green energy is new clean energy from renewable sources such as; Sun, wind, and water. The price of electricity in it is still higher than the price of energy generated from conventional oil sources. Some of the types of renewable resources are discussed below and will be emphasized in this study:

Photovoltaic (PV)

The quantity of energy that strikes the earth's surface per unit area is known as solar irradiance. Due to the earth's rotation in relation to the sun, this quantity will fluctuate daily and annually for a certain place. The geographic location (latitude and longitude) and the weather conditions also affect how much solar radiation is present. The key factor influencing how much solar energy reaches the earth's surface is cloud cover. Solar energy may be produced depending on the brightness of the sun, the amount of daylight, and the state of the sky. Since it reacts to these changes quickly as a result of this dependence, solar irradiance is primarily characterized by stumpy temporal fluctuations. Due to a number of variables, it is challenging to forecast the probability distribution of irradiance variations. Since solar panels' efficiency varies from panel to panel, it makes sense to anticipate how much radiation each solar panel would absorb [11].

Wind turbines (WT)

There is a lot of untapped wind energy potential in many developing nations and growing economies. In many places, producing electricity from wind energy is more affordable than using thermal power plants. It lessens its negative effects on the environment and the climate, lessens reliance on imported fossil fuels, and improves the security of the energy supply [12].

The power generated by a wind turbine is calculated by a simple application of the kinetic energy equation KE=1/2mv^2 through a cross-sectional area A. The equation of the available power in Watts is given:

$$P = \frac{1}{2}\,\rho V^3 A = \frac{1}{2}\rho V^3 \frac{\pi d^2}{4} \qquad (1)$$

Where V is the wind speed in meters per second (m/s), ρ is the density of air in kg/m3 (typically 1.225 kg/m3 at 15.55°C and 101,325 Pa), and d is the rotor diameter in m.

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Comparison between Central Generation and Distributed Generation

A comparison between centralized generation (CG) and distributed generation (DG) in the future electrical network infrastructure. CG was the dominant use in the legacy system, presenting significant energy consumption but with a variety of issues including cost, sustainability, and long-term resilience challenges. On the other hand, DG is smaller in design and power generation, and it is mainly designed for Renewable Energy Sources (RES) such as wind and solar energy resources, shows Table 1 below of a summary of the most important points of comparison between centralized generation (CG) and distributed generation (DG) [13]. A comparison between centralized generation (CG) and distributed generation (DG) is depicted in Table 1.

Table 1. Centralized generation and distributed generation:

Factors	CG	DG
Location	Centrally located.	It is not location bound. It is distributed.
Transmission	High voltage transmission is mandatory. High losses and transmission failure.	Only distribution required. Reduced capital cost.
Emission	High with more output Power.	Low for intermittent source. High for fossil fueled units but has power output limitation.
Technologies	Basically, gas and hydro turbine.	The technologies adopted in DG comprise small gas turbines, micro-turbines, fuel cells, wind and solar energy, biomass, small hydro-power
Cost	High variable cost. High maintenance cost.	Low variable cost. Low maintenance cost.
Reliability	High with more output power.	Low reliability but has power output limitation.

III. POWER SYSTEM MODELING (METHODOLOGY)

Power flow studies can provide a number of systematic mathematical approaches for determining complex bus voltages. Through these voltages, it is possible to determine the power flow in the branches and generators' distribution and loads under steady-state conditions. The power flow analysis in this thesis is based on the steady-state operation of the power system with and without the presence of the distributed generation systems induced through these values the number of electrical losses on the networks is determined by distribution. Power flow analysis is widely used by electrical power transmission professionals during the planning and operation phases of electrical power transmission systems.

Mathematical Model

It should be noted that, before starting the load flow analysis, the entire network must be designed with all generators, loads, and transmission lines. The power grid consists of elements such as transformers, distribution generators, loads, transmission lines, cables, and generators.Suppose we have two buses i and j, the complex power flows in the line from bus i to bus j is given by:

$$S_{ij} = P_{ij} + Q_{ij} = V_i(I_{ij})^*$$

$$S_{ij} = V_i \angle \theta i \left[\frac{V_i \angle \theta i - V_j \angle \theta j}{Z_{ij}}\right]^* \quad (2)$$

The active (P_{ij}) and reactive (Q_{ij}) powers that come out from bus i to bus j are given by:

$$P_{ij} = \text{Real}\,[S_{ij}] = \frac{(Vi)^2 \cos(\theta ij)}{Z_{ij}} - \frac{Vj\, Vi \cos(\theta ij + \theta i - \theta j)}{Z_{ij}} \quad (3)$$

$$Q_{ij} = \text{Imaginary}\,[S_{ij}]$$

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$$= \frac{(Vi)^2 \sin(\theta ij)}{Z_{ij}} - \frac{Vj\, Vi \sin(\theta ij + \theta i - \theta j)}{Z_{ij}} \quad (4)$$

For a typical power system that consists of n number of buses, the net injected power equations in the polar formula for each bus can be written:

$$P_i = \sum_{j=1}^{n} \frac{|Vi||Vj|}{Z_{ij}} \mathrm{Cos}(\theta ij - \delta i + \delta j) \quad (5)$$

$$Q_i = -\sum_{j=1}^{n} \frac{|Vi||Vj|}{Z_{ij}} \mathrm{Sin}(\theta ij - \delta i + \delta j) \quad (6)$$

The solution techniques for the distribution network power flow problems are classified under two major reference groups namely the phase frame approach and sequence frame approach.

The Forward and Backward sweep method, Compensation method, Implicit Gauss method, modified Newton-Raphson methods, or any other miscellaneous power flow methods are the different algorithms used under each reference frame. Attention is given to the techniques to deal with balanced/unbalanced, radial/weakly meshed/mesh configuration, with or without Distributed Generation (DG), and convergence criteria.

The most common method used to solve a power system flow problem is the Newton Raphson Method (NR), which is used to solve a set of nonlinear algebraic methods Equations. Because it is one of the fastest methods of square convergence with a root.

The total active power losses in a distribution system with N buses as a function of active and reactive power injections at all buses can be calculated as follows:

$$P_{loss} = \sum_{i=1}^{N} \sum_{j=1}^{N} [\alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j - P_i Q_j)] \quad (7)$$

Where $\alpha_{ij} = \frac{r_{ij}}{V_i V_j} \cos(\delta_i - \delta_j)$; $\beta_{ij} = \frac{r_{ij}}{V_i V_j} \sin(\delta_i - \delta_j)$; $V \angle \delta_i$ is complex voltage at bus i; $rij + jxij = Zij$ is the ij the element of [Zbus] impedance matrix; Pi and Pj are active power injections at buses i and j, respectively; $Qi$and $Qj$are reactive power injections at buses i and j respectively.

This section briefly describes an analytical expression developed in to calculate different types of DG units for minimizing power losses when the DG power factor is pre-specified. Here, the active and reactive power injections at bus i where the DG unit is installed are respectively given as:

$$P_i = P_{DGi} - P_{Di} \quad (8)$$

$$Q_i = Q_{DGi} - Q_{Di} = a_i P_{DGi} - Q_{Di} \quad (9)$$

Where $Q_{DGi} = a_i P_{DGi}$, P_{DGi} and Q_{DGi} are respectively the active and reactive power injections from DG unit at bus i, a_i = (sign) tan $(cos^{-1}(Pf_{DGi}))$ with {sign = +1: DG unit injecting reactive power, sign = -1: DG unit consuming reactive power}. P_{Di}andQ_{Di} are respectively the active and reactive power of load at bus i; power factor of DG Pf_{DGi} is the operating the power factor of DG unit at bus i.

$$P_{loss} = \sum_{i=1}^{N} \sum_{j=1}^{N} [\alpha_{ij}((P_{DGi} - P_{Di})P_j + (a_i P_{DGi} - Q_{Di})Q_j) + \beta_{ij}((a_i P_{DGi} - Q_{Di})P_j - (P_{DGi} - P_{Di})Q_j)] \quad (10)$$

IV. SYSTEM DESCRIPTION

Electric Power System and the National Transmission Grid in Jordan

In the Jordanian electric grid, three distribution companies are EDCO, (JEPCO), and (IDECO). National Electricity Power Company (NEPCO) delivers bulk power to these companies as well as to large industrial customers. Power is generated by many different generating companies such as Central Electricity Generating Company (CEGCO), Al Samra Electric Power Company (SEPCO), Amman Asia Electric Power Company (IPP3), and many others].In 2020, the total peak demand was 3,630 MW, a growth rate of 7.4% over the previous year [15].

Case studies at Low Voltage Distribution Networks

The proposed assumptions in this study will be applied to the low and medium voltage network in one of the previously mentioned distribution networks, where Jordan was divided into three regions and each of the electricity distribution companies was given the geographical privilege to work in it and within the licenses granted to it by the Energy and Minerals Regulatory Commission (EMRC), through its geographically dispersed distribution network.A case study was

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selected in different areas within the concession areas at Low Voltage Distribution Networks, three substations were selected at low voltage, as follows:

Substation (1): Energy is transferred to LV customers using (33/0.4 kV) substations; which are substation number (I-002425) with a capacity of (630 kVA), and the lengths of cables of different types and sizes of (OHL) totaling about (794.52) m, and total generated energy related to the substation from distribution generators (DG) from renewable energy sources is (40.5 KW), As shown in Figure 1 simple single-line diagrams with DG, and as shown in Figure 4 the substation mentioned above.

Substation (2): Energy is transferred to LV customers using (33/0.4 kV) substations; which are substation number (I-002413) with a capacity of (100 kVA), and the lengths of cables of different types and sizes of (OHL) totaling about (102.8) m and the size, and total generated energy related to the substation from distribution generators (DG) from renewable energy sources is (70 KW) Figure 5.

Substation (3): Energy is transferred to LV customers using (33/0.4 kV) substations; which are substation number (I-012063) with a capacity of (630 kVA), and the lengths of cables of different types and sizes of (OHL) totaling about (1438.8) m, and total generated energy related to the substation from distribution generators (DG) from renewable energy sources is (35 KW) Figure 6.

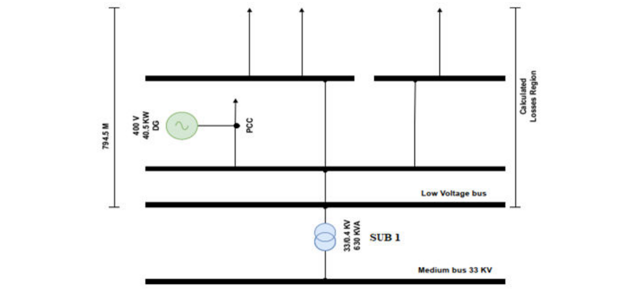

Fig. 4. LV Network of substation (1)

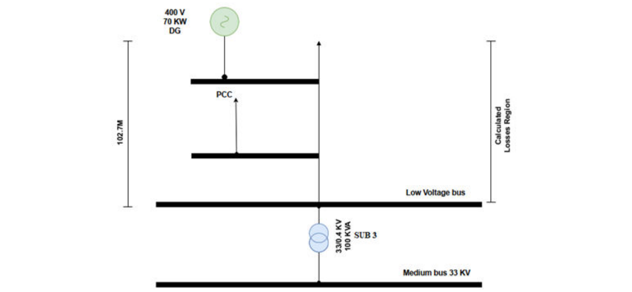

Fig. 5. LV Network of substation (2)

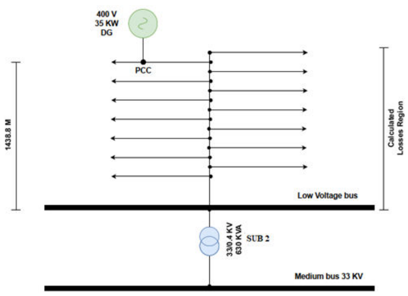

Fig. 6. LV Network of substation (3)

V. RESULTS

LV Network of substation (1)

Table 2 summarizes the technical losses ratio, cable loading, and related information at LVBUS for a I-002425 substation. From Table 2, note that the technical losses rate is high in the LV networks of substation I-002425 where we note that the highest value of losses was when the feeder was fully loaded, as well as the distribution generators were not working.

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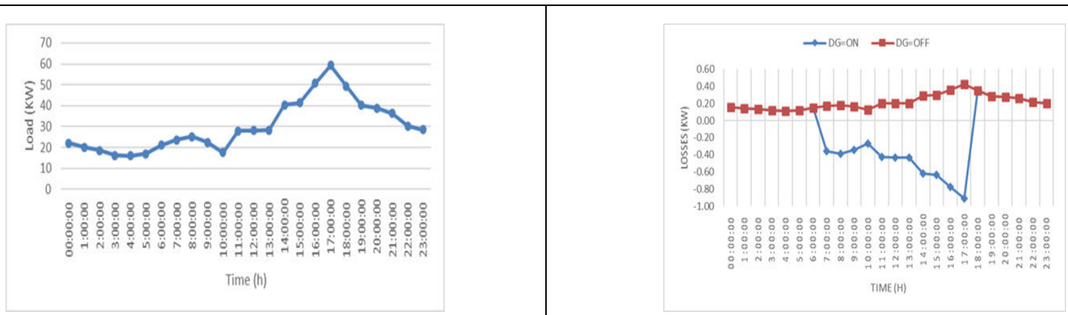
Table 2. Technical losses ratio, cable loading, and related information at LVBUS for a substation (1)

Cases	I(A)	KVA	Load (KW)	KVAR	Losses (kW)	Losses%
DG=OFF	35	24	21	13	0.15	0.0071
DG=ON	34	24	-20	13	0.3	-0.0153

Load and Losses Profile Results for Feeder Long Term Dynamic Analysis (LTD), From a substation (1) is shown in Figure 7, respectively. Pregnancy The results of the losses profile are recorded at the LVBUS point.



(a) (b)

Fig .7. Results of Load and Losses Profile for Cases 1 and 2: load profile (KW) versus time (a); losses profile (KW) versus time (b) for sub 1

It has been shown in Figure 7. (a) that the pregnancy progressed for 24 hours for the first sub-station, before applying the presence of the distribution generators, where the highest pregnancy during this period was recorded at 17 pm, during the peak period in the winter season in Jordan. The Figures show the highest feeder load and losses value on the LVBUS, as we note that the best losses improvement occurred when the feeder was fully loaded, and the distribution generators running.

LV Network of substation (2)

Table 3 summarizes the technical losses ratio, cable loading, and related information at LVBUS for a substation (2).

Table 3. Technical losses ratio, cable loading and related information at LVBUS for substation (2).

Cases	I(A)	KVA	Load (KW)	KVAR	Losses (kW)	Losses%
DG=OFF	2.82	2	2	0.0003	0.002	0.001
DG=ON	94.2	66	-66	0.23	1.12	- 0.016

Load and Losses Profile Results for Feeder Long Term Dynamic Analysis (LTD), From a substation (2) is shown in Fig.8 (a) and (b), respectively. Pregnancy The results of the loss profile are recorded at the LVBUS point.

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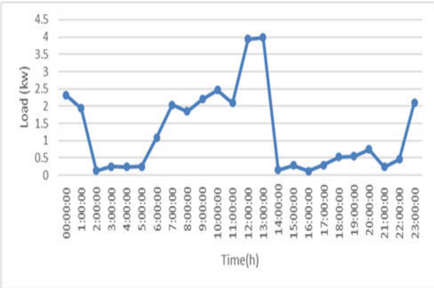
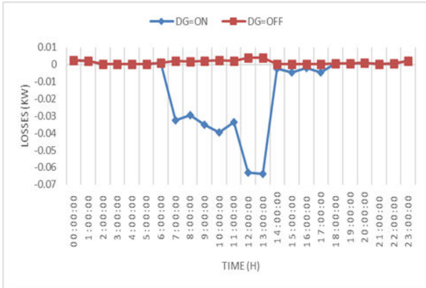


(a)



(b)

Fig .8. Results of Load and Losses Profile for Cases 1 and 2: load profile (KW) versus time (a); losses profile (KW) versus time (b) for sub 2

Figure 8 shows the load progression over 24 hours for the second substation before the application of the presence of distribution generators, with the highest load recorded during this period, was recorded at 12 am. This is because Substation No. 2 has unstable loads and is not continuous around the clock, because it feeds a livestock farm. It has been illustrated in Figure 8 (a) and (b) has different payload and losses. The figures show the highest feeder load and losses value on LVBUS, where we note the best improvement in losses is when the feeder was fully loaded, also the distribution generators working.

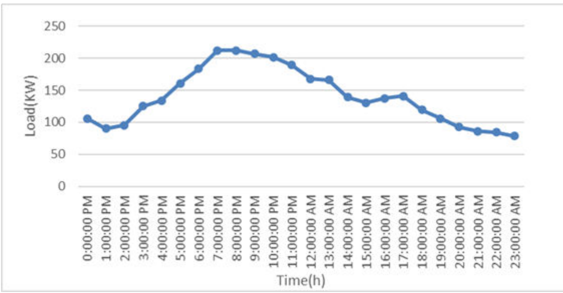
LV Network of substation (3)

From Table 4, note that the technical losses ratio is high in the LV networks of substation (3) where we note that the highest value of losses was when the feeder was fully loaded, as well as the distribution generators were not working.

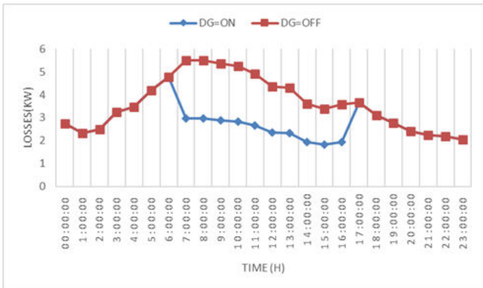
Table 4. Technical losses ratio, cable loading and related information at LVBUS for substation (3).

Cases	I(A)	KVA	Load (KW)	KVAR	Losses (kW)	Losses%
DG=OFF	362.2	257.2	228.61	119.16	5.91	0.026
DG=ON	314.7	224.1	190.43	118.14	2.73	0.014

Load and Losses Profile Results for Feeder Long Term Dynamic Analysis (LTD), from a substation (3) is shown in Figure 9 (a) and (b), respectively. Pregnancy The results of the losses profile are recorded at the LVBUS point.



(a)



(b)

Fig .9. Results of Load and Losses Profile for Cases 1 and 2: load profile (KW) versus time (a); losses profile (KW) versus time (b) for sub 3

Figure 9 shows the load progression over 24 hours for the second substation before the application of the presence of distribution generators, with the highest load recorded during this period in the morning. This is due to substation No. 3 feeding a well to pump water, as the peak work of these pumps is during the morning period.It has been shown in Figure 9. (a) and (b) has a different height loading and losses. The Figures show the highest load of the feeder and the

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value of losses on the LVBUS. We note that the best loss improvement occurred when the feeder was fully loaded, and the distribution generators running.

Comparison of results between the three substations

Table 5 below, shows a comparison between the results of the energy analysis that was studied on three substations of different lengths and loads, as well as the types of these loads.

Table 5. Comparison of results between the three substations.

Cases	lengths of cables (m)	DG (Kw)	Losses (kw) (DG OFF)	Losses (kw) (DG ON)	Losses (%) (DG OFF)	Losses (%) (DG ON)
Sub 1	794.52	45.5	0.15	0.3	0.0071	-0.0153
Sub 2	102.8	70	0.002	1.12	0.001	-0.016
Sub 3	1438.8	35	5.91	2.73	0.026	0.014

Through the comparison shown in Table 5, we significantly decrease the values of losses in kilowatts from operating the distributed generators in substation (3), in contrast to what happened in substations (1) and (2), and the reason for this is due to the loading of the line and the capacity of the distribution generators connected to the feeder and the lengths of the feeders.But in terms of the percentage of losses, we notice in all sub-stations a slight improvement in the percentages of losses due to the operation of distributed generators.

VI. CONCLUSIONS

In this paper, the effect of connecting distribution generators from renewable energy sources on low voltage networks is explained. Where two cases were proposed in which the effect of distributed generators from renewable energy sources on technical losses on the low voltage network, with and without distribution generators, also with and without load on substations. This paper can be concluded. the technical losses ratio on low voltage networks in the proposed operation of the modes DG=ON is less than that in the current operating status DG=Off due to the entry and operation of the distribution generators at their full capacity.

Accordingly, the presence of distribution generators on the distribution network, especially the low voltage, leads to an improvement in the rates of electrical losses, unlike those networks that do not have distribution generators with renewable energy sources.

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